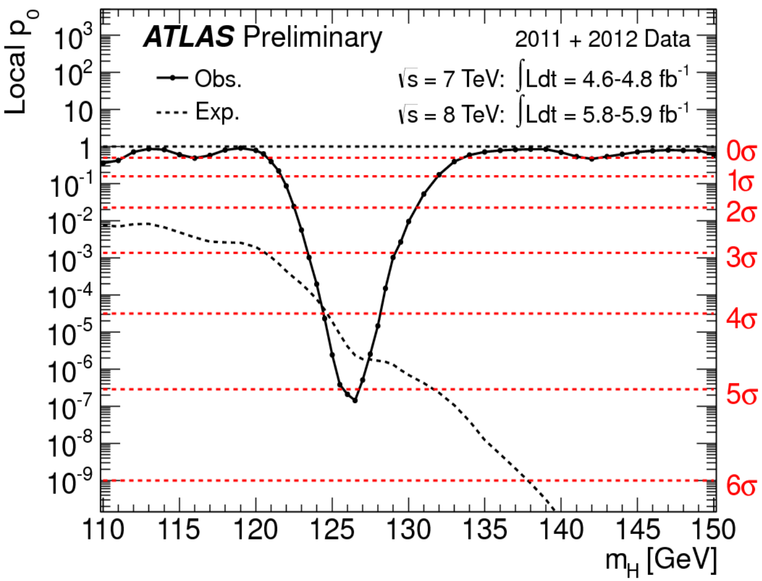
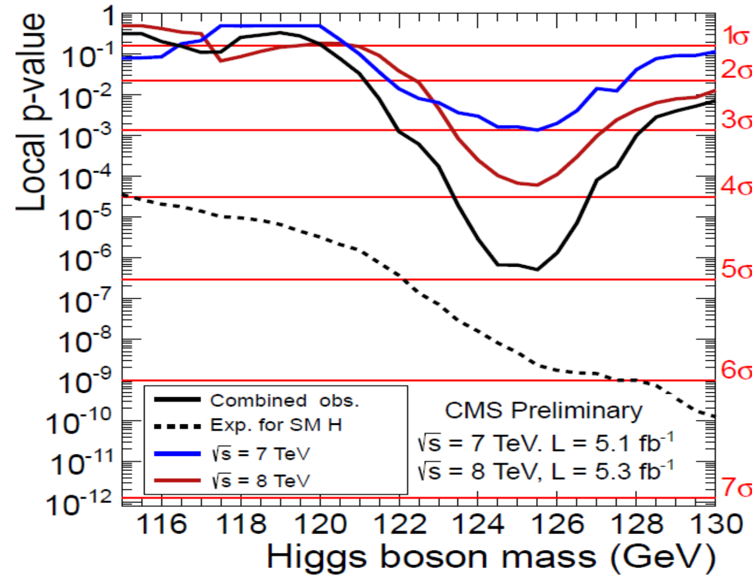
Preliminary study on the measurement of Higgs with CEPC

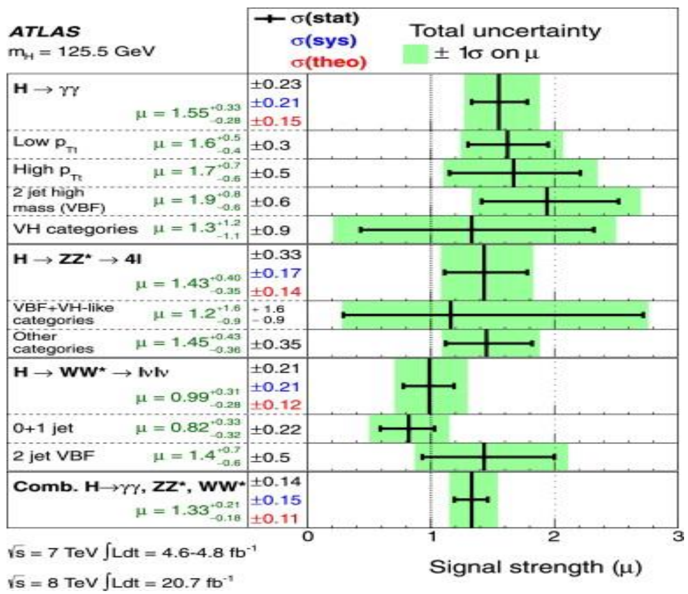
Yaquan Fang (IHEP, Beijing)
On behalf of the CEPC collaboration

the Workshop of the Future of High Energy Physics
IAS, Hongkong, Jan 19-22, 2015

Motivation

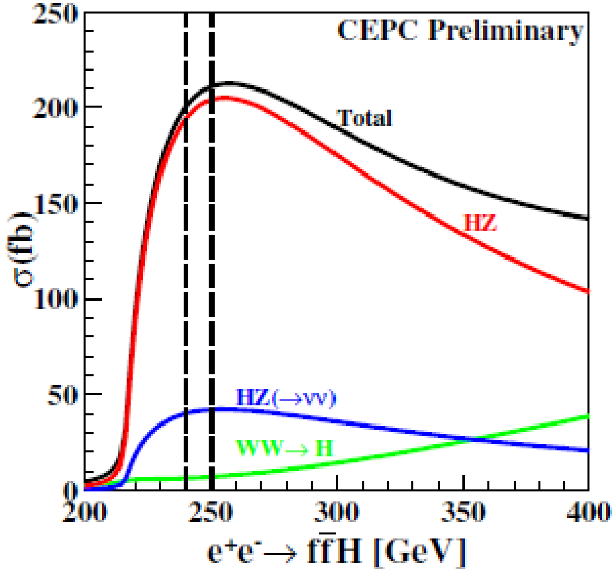


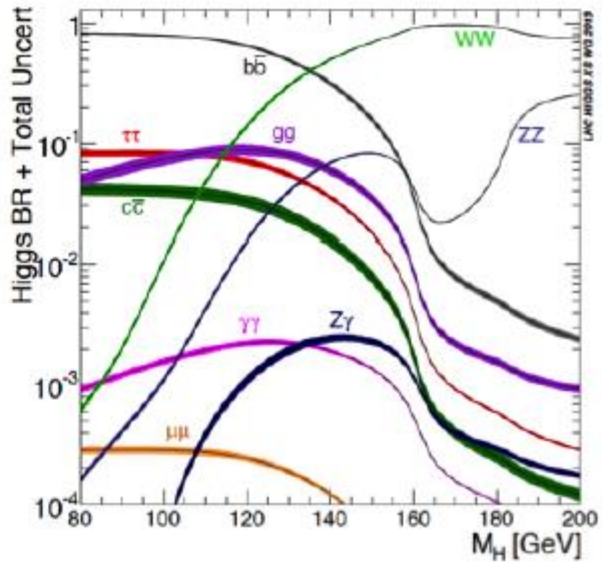


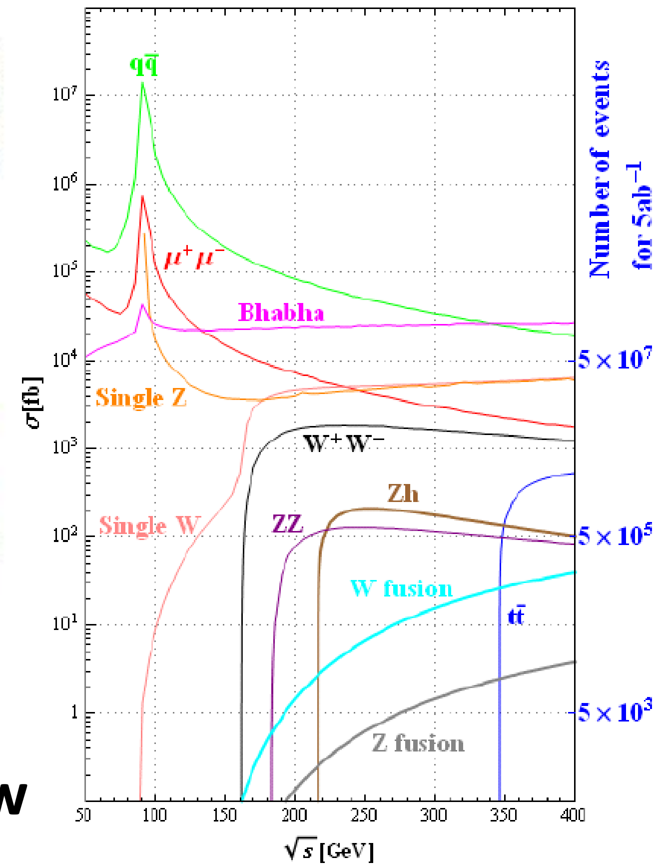


- **The discovery of Higgs in 2012 is a milestone of particle physics.**
- **The further measurements of the properties of the particle confirm it is SM Higgs.**
- **The precision of Higgs measurement is important since the new physics (NP) could introduce a deviation ($\Delta \sim cv^2/M_{NP}^{\ 2}$) which is proportional to $1/M_{NP}^2$.**
- **With LHC, some systematics shows the bottleneck, e.g. theoretical sys. , for the precise measurements of the Higgs coupling etc…**
- **A lepton collider Higgs factory can provide a direct measurement of the Higgs xsection.**
  - **One of the proposals is the Circular Electron Positron Collider (CEPC).**

SM Higgs Productions, branching ratio, Bkg process







✓ At e^+e^- collider, the dominant production is from HZ, the WW/ZZ fusions contribute a few percent of the total cross-section.

✓ e^+e^- collider provides a good opportunity to measure the bb, invisible decay of Higgs.

✓ For 5 ab^{-1} data with CEPC, 1M Higgs, 10M Z, 100M W are produced.

CEPC

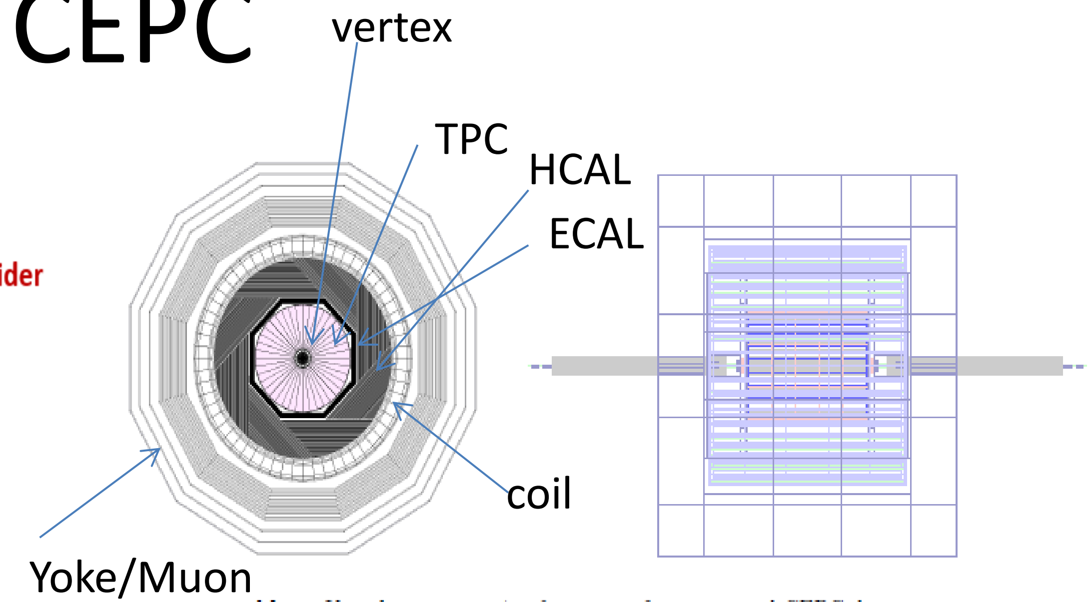
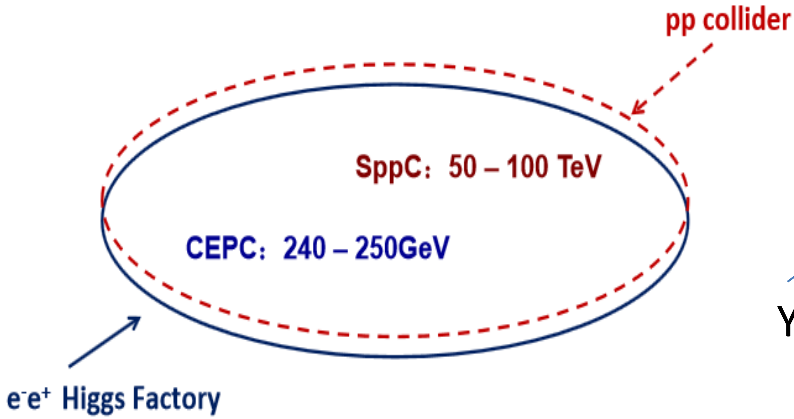


Table 2. Key characteristic/performance of a conceptual CEPC detector.

Geometry acceptance	TPC (97%), FTD (99.5%)
Tracking efficiency	$\sim$ 100% within geometry acceptance
Tracking performance	$\Delta(1/p_T) \sim 2 \times 10^{-5}$ (1/GeV)
ECAL intrinsic energy resolution	$16\%/\sqrt{E} \oplus 1\%$ (GeV)
HCAL intrinsic energy resolution	$60\%/\sqrt{E} \oplus 1\%$ (GeV)
Jet energy resolution	3-4%
Impact parameter resolution	5 μm

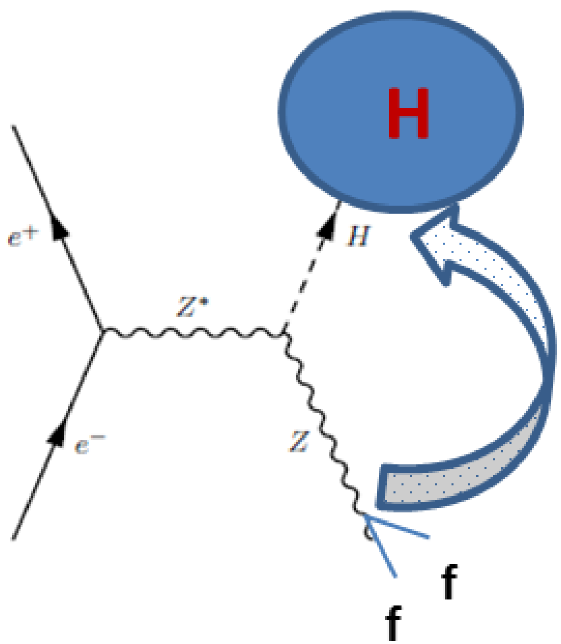


- ✓ **A CEPC (phase I)+ Super proton-proton Collider (SPPC) was proposed in IHEP, Sept. 2012**
- ✓ **Ecm ~240-250 GeV, Lum 5 ab^{-1} for 10 years**

- ✓ **An international linear detector (ILD) like detector is considered in the pre-CDR study.**

Direct measurement of Higgs cross-section

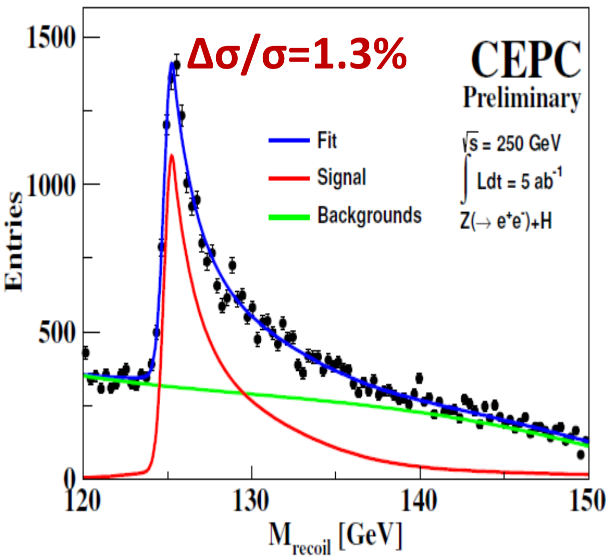
$$M_{\text{recoil}}^2 = (\sqrt{s} - E_{ff})^2 - p_{ff}^2 = s - 2E_{ff}\sqrt{s} + m_{ff}^2$$



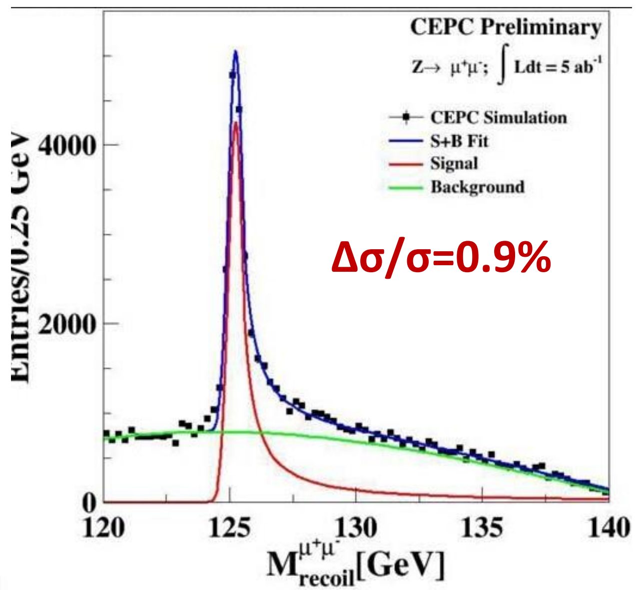
- ✓ For this model independent analysis, we reconstruct the recoil mass of Z without touching the other particles in a event.
- ✓ The M_{recoil} should exhibit a resonance peak at m_H for signal; Bkg is expected to smooth.
- ✓ The best resolution can be achieved from $Z(\rightarrow e^+e^-, \mu^+\mu^-)$.

Direct measurement of Higgs cross-section

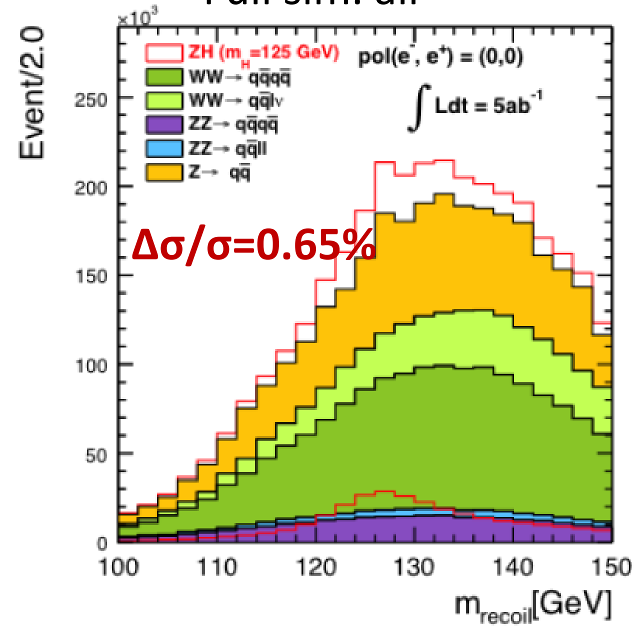
Full sim. signal



Full sim. signal



Full sim. all



- ✓ **ZZ,WW,Zγ and bhabha for Z->ll are dominant bkgs for Z(->ll)H.**
- ✓ **For hadornic decay of Z, Z(->qq) and WW(qqqq,qqlv) are the most dominant bkgs as the right plot shows.**
- ✓ **The combined precision with three channels is $\Delta\sigma/\sigma=0.5\%$**

Measurements of (σ▪Br)/(σ▪Br) and ΔBr/Br

1. **A likelihood L(Θ) is built :**

$$f(n_{cb}, a_p \mid \phi_p, \alpha_p, \gamma_b) = \prod_{c \in \text{channels}} \prod_{b \in \text{bins}} \text{Pois}(n_{cb}|\nu_{cb}) \cdot G(L_0|\lambda, \Delta_L) \cdot \prod_{p \in \mathbb{S}+\Gamma} f_p(a_p|\alpha_p)$$

Shape info. for the discriminating Variables considered.

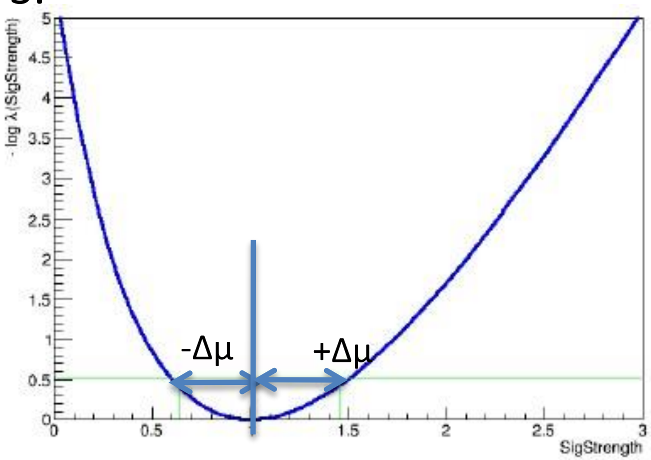
$$L(\boldsymbol{\theta}) = \prod_{i=1}^{n} f(y_i; \boldsymbol{\theta})$$

2. **A profile likelihood ratio λ(μ) (μ signal strength in our case: σ▪Br) is constructed to estimate the parameters of interest:**

$$\lambda(\mu) = \frac{L(\mu, \hat{\hat{\boldsymbol{\theta}}})}{L(\hat{\mu}, \hat{\boldsymbol{\theta}})} \qquad 0 \leq \lambda \leq 1$$

μ is the test hypothesis (μ=0,1 correspond to bkg /signal+bkg only hypothesis)

3.



- ✓ **If the likelihood ratio follows a χ^2 distribution, the significance can be approximately computed as sqrt[-2*log(λ)] with μ=1;**
- ✓ **Similarly, one can scan μ (Minuit) and the error of μ is the distance of x-axis between μ=1 and the point on the curve corresponding to –log(λ)= 0.5.**
- ✓ **For the measurement of Br, the uncertainty from total xsection obtained from previous page is incorporated into the fit.**

Measurement of Higgs width

- **Method 1: Higgs width can be determined directly from the measurement of σ(ZH) and Br. of (H->ZZ*)**

$$\Gamma_H \propto \frac{\Gamma(H \to ZZ^*)}{\mathrm{BR}(H \to ZZ^*)} \propto \frac{\sigma(ZH)}{\mathrm{BR}(H \to ZZ^*)}$$

  - **But the uncertainty of Br(H->ZZ*) is relatively high due to low statistics.**

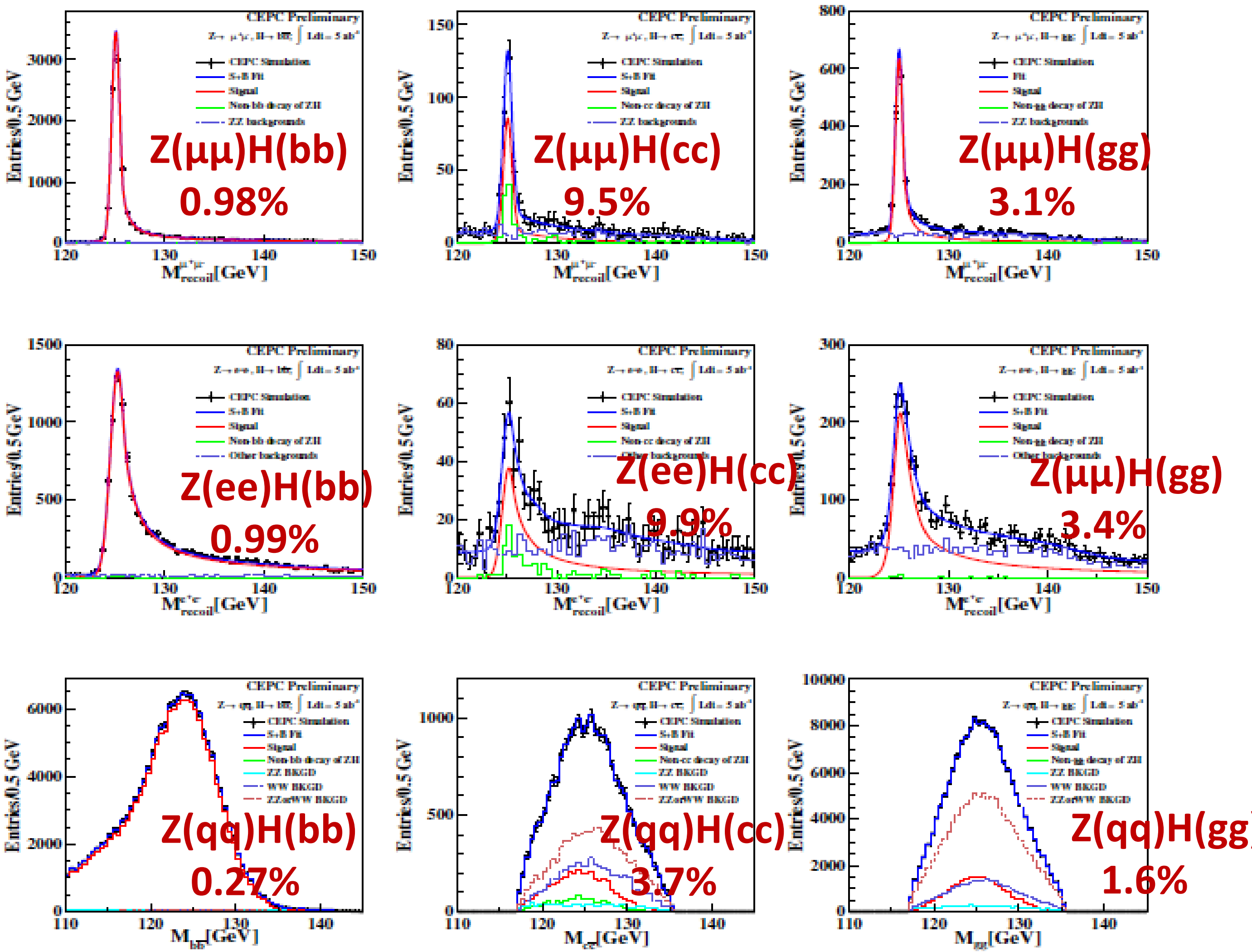
- **Method 2: It can also be measured through:**

$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{BR(H \to bb)} \qquad \sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b}) \propto \Gamma(H \to WW^*) \cdot \mathrm{BR}(H \to bb) = \Gamma(H \to bb) \cdot \mathrm{BR}(H \to WW^*)$$

$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{\mathrm{BR}(H \to bb)} \propto \frac{\sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b})}{\mathrm{BR}(H \to b\bar{b}) \cdot \mathrm{BR}(H \to WW^*)}$$

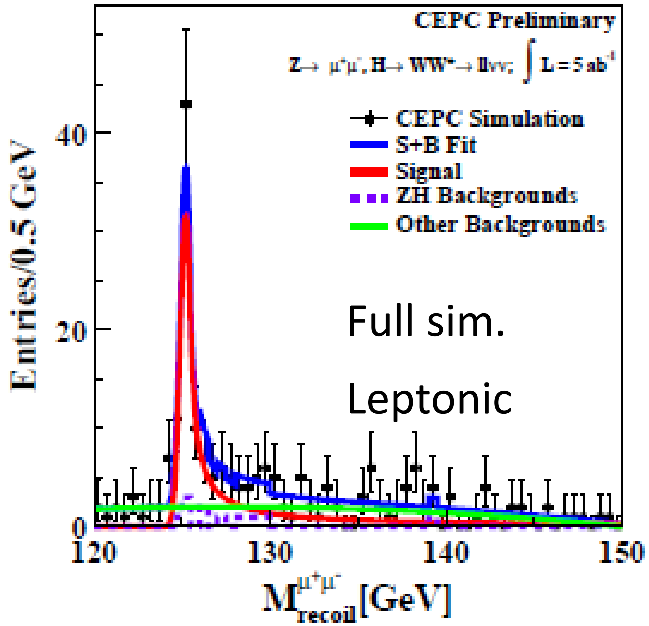
- **These two orthogonal methods can be combined to reach the best precision.**

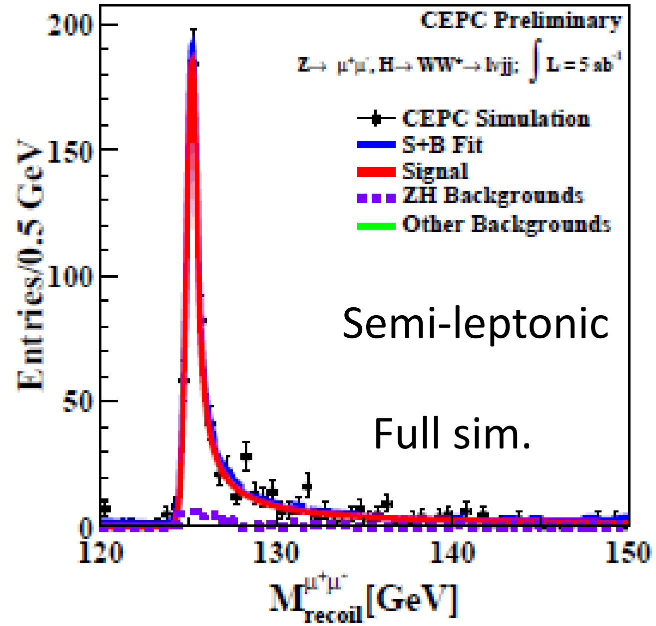
Measurement of Δ(σ▪Br)/(σ▪Br) of ZH(jj)



- ✓ **For Z(μμ),Z(ee), the recoil mass of Z is used as a discriminating variable to benefit from the good resolution of leptons.**
- ✓ **Fast simulated samples are used in this study.**
- ✓ **The combined precisions of for the measurement of H->bb,cc,gg are 0.25%, 3.2%, 1.32% respectively.**

Measurement of Δ(σ▪Br)/(σ▪Br) of ZH(WW)



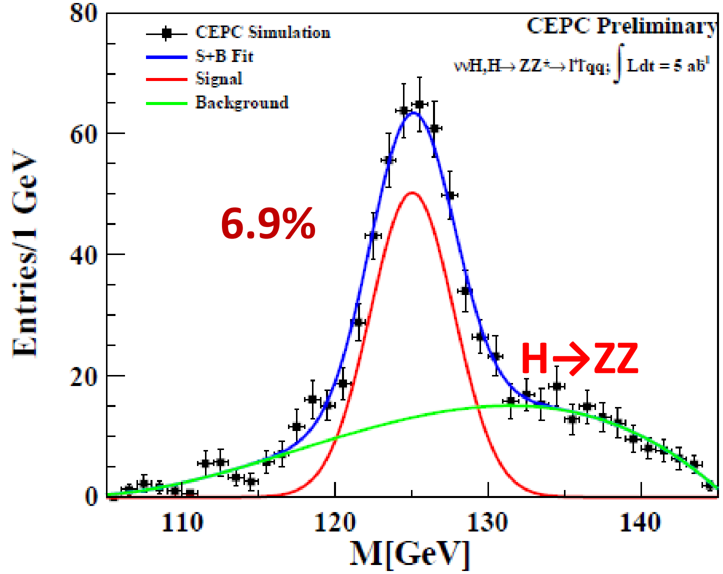


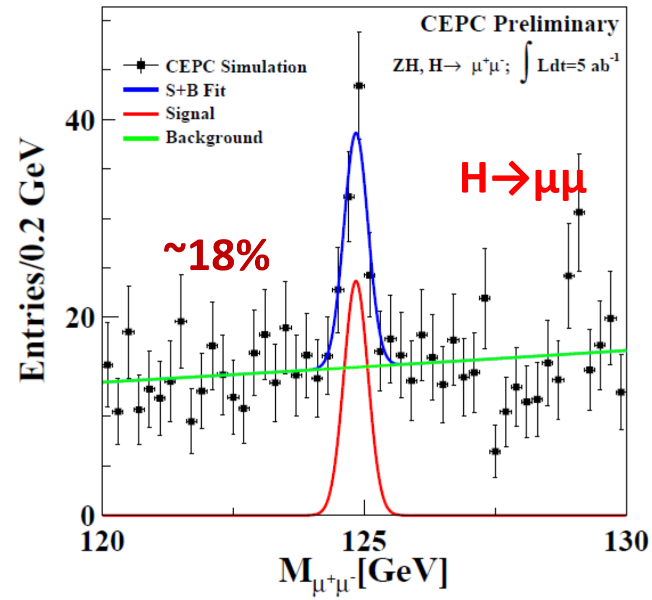
Channel	Precision	Comment
$Z \to \mu\mu, H \to WW^* \to \ell\nu qq, \ell\ell\nu\nu$	4.9%	CEPC Full Simulation
$Z \to ee, H \to WW^* \to \ell\nu qq,\ \ell\ell\nu\nu$	7.0%	Estimated
$Z \to \nu\nu, H \to WW^* \to qqqq$	2.3%	Extrapolated from ILC result
$Z \to qq, H \to WW^* \to \ell\nu qq$	2.2%	Extrapolated from ILC result
Combined	1.5%	

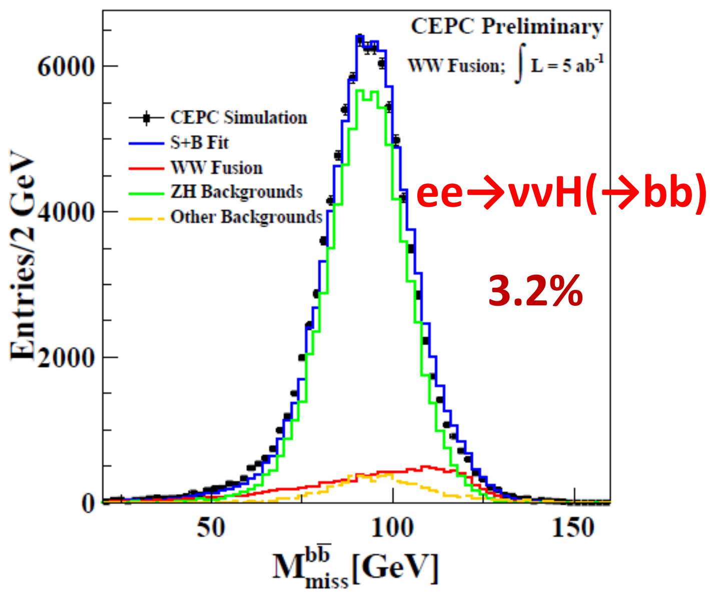
- ✓ **This channel is necessary for the Higgs width measurement.**
- ✓ **Leptonic and semi-leptonic decays of W bosons are used in the analyses.**
- ✓ **MVA technique is implemented in the Z->(ll,ee) to further suppress ZZ bkg.**
- ✓ **The combined precision is 1.5%.**

Expected measured precision of σ▪Br from other channels

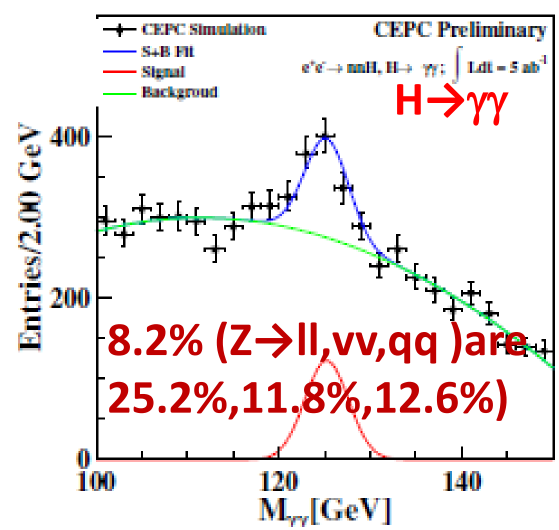
4.3% including other processes (extrapolated from FCC-ee)







$$\frac{\delta(E)}{E} = \frac{16\%}{\sqrt{(E)}} \oplus 1\%$$

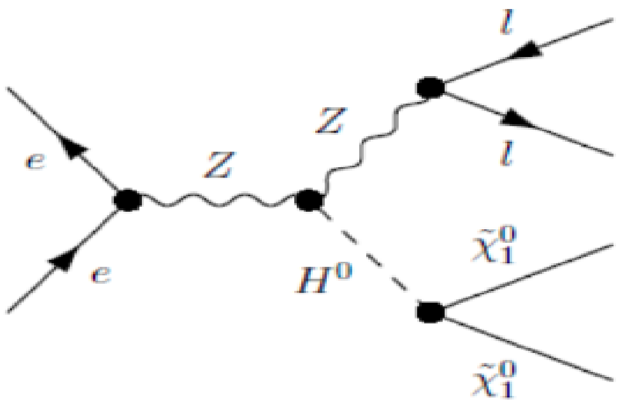


One way to Measure Γ_H

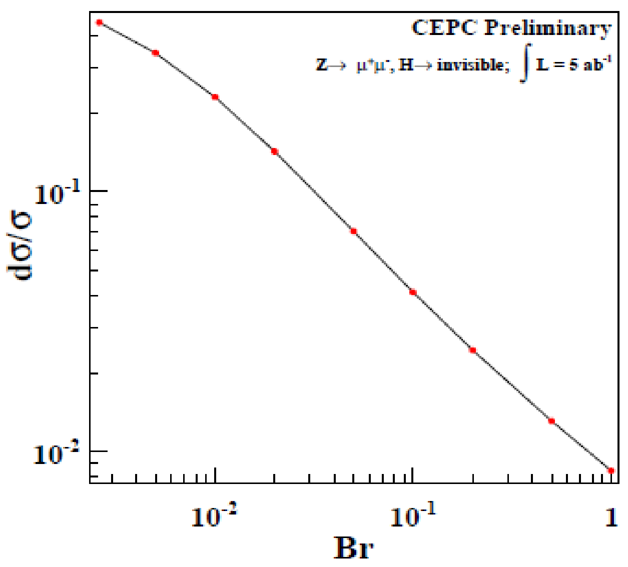
$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{\mathrm{BR}(H \to bb)} \propto \frac{\sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b})}{\mathrm{BR}(H \to b\bar{b}) \cdot \mathrm{BR}(H \to WW^*)}$$

Measurement of the invisible decay of Higgs

- Invisible can be produced e.g. by the invisible decay of Higgs,NMSSM,2HDM+singlet…
- For CEPC, the recoil mass method provides a chance to have the direct measurement.



Precision of invisible decay as a function of Br.



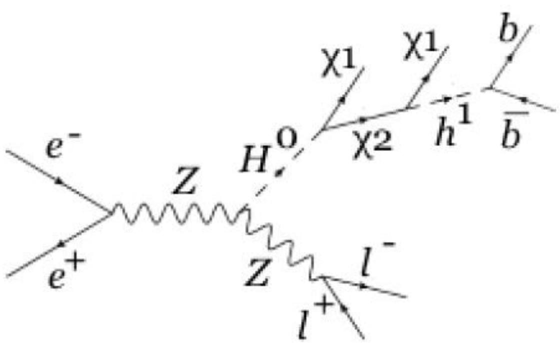
Measurement of the exotic decay of Higgs

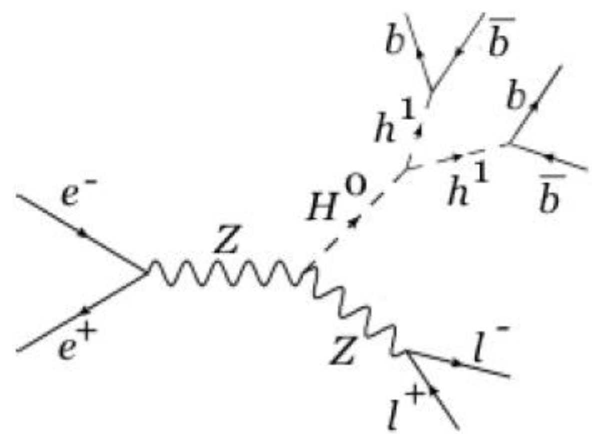
- For the exotics searches, we tried semi-invisible, visible decays,
- one can achieve 9.4σ, 8.43σ with

 5 ab^{-1} lum., assuming the corresponding Br.

 of H->$\chi_1\chi_2$ and H->hh->4b are 0.2%, 0.048%

respectively.

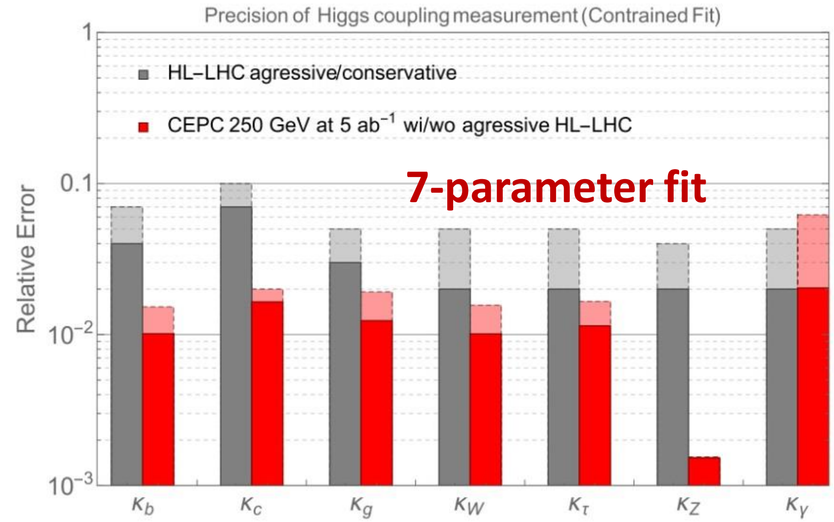




Summary of the precision for the measurement of Higgs

ΔM_H	Γ_H	$\sigma(ZH)$	$\sigma(\nu\nu H) \times \mathrm{BR}(H \to bb)$
5.5 MeV	2.7%	0.5%	2.8%

Decay mode	$\sigma(ZH) \times \mathrm{BR}$	BR
$H \to bb$	0.25%	0.56%
$H \to cc$	3.2%	3.2%
$H \to gg$	1.3%	1.4%
$H \to \tau\tau$	1.2%	1.3%
$H \to WW$	1.5%	1.6%
$H \to ZZ$	4.3%	4.3%
$H \to \gamma\gamma$	8.2%	8.2%
$H \to \mu\mu$	22%	22%
$H \to \mathrm{inv}$	0.28%	0.28%



- ✓ **With combination of σ▪Br of ννH(→bb) /Br(H->bb)/Br(H->ww) and the direct measurement, one can obtain the decay width of Higgs with the precision at 2.7%.**
- ✓ **The measurement of Br is done by introducing the uncertainty of xsection of ZH from the direct measurement (no theoretical uncertainty needs to be taken into account).**
- ✓ **Most precisions are a few percent or lower (bb, invisible), allowing us to be sensitive to BSM deviation (Jianming's talk yesterday).**
- ✓ **In comparison with HL-LHC, CEPC is expected to have much better performance in the measurements of the coupling constants in particular for κ_z .**

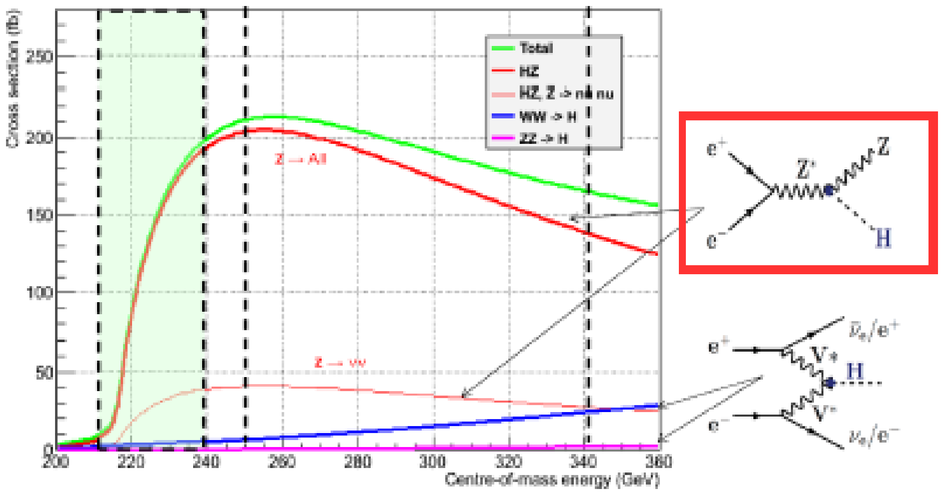
Conclusion

- A very preliminary study on the measurement of Higgs at CEPC has been done and is being documented in the Pre-CDR.
- As one e+e- collider, CEPC provides an exceptional opportunity to have a direct measurement of Higgs cross-section with a precision at ~0.5% for 5 ab^{-1} data.
- The recoil mass method by reconstructing only the Z boson also provides the best probe into H->invisible decays and search for dark matter and exotics produced in the Higgs decays.
- CEPC can measure the Higgs decays and couplings with precisions at a few percent or sub-percent level, (e.g. h->bb at 0.56% for Br measurement), sensitive enough to some new physics deviation.

Backup Slides

Why an e^+e^- Higgs factory

$$g/g_{SM} \sim 1 + \delta(1\text{TeV}/\Lambda_{NP})^2$$



NP model	δ(hVV)	δ(htt)	δ(hbb)
Extra Higgs	<1%	<1%	1.7%
Composite Higgs	8%	~ 10%	~ 10%
Mixed in Singlet	6%	6%	6%
MSSM	< 1%	3%	10%-100%
Top parter	0.8 – 2.9%		
...			

ILCTDR, 1310.8361 [hep-ex]...

...Higgs couplings: **absolute** measurements to percentage level...
... a vision of New Physics Landscape at TeV era...

Measurement of Δ(σ▪Br)/(σ▪Br) of ZH(jj)

Table 7. Expected event yields for signal and backgrounds for ZH production with $H \to bb/cc/gg$, normalized to 5 ab^{-1}. The signal efficiency as well as the expected precision of the measurement ($\Delta(\sigma \times \mathrm{BR})/\sigma \times \mathrm{BR}$) is also shown.

Channel		$H \to bb$	$H \to cc$	$H \to gg$
$Z \to \mu\mu$	signal/efficiency	10773/52.8%	283/31.2%	1815/58.6%
	background	469	441	1275
	$\Delta(\sigma \times \mathrm{BR})/\sigma \times \mathrm{BR}$	0.98%	9.5%	3.1%
$Z \to ee$	signal	10853/49.4%	319/30.9%	1776/54.6%
	background	723	685	1873
	$\Delta(\sigma \times \mathrm{BR})/\sigma \times \mathrm{BR}$	0.99%	9.9%	3.4%
$Z \to qq$	signal	148749/35.9%	3887/20.4%	25564/41.7%
	background	7584	17219	146348
	$\Delta(\sigma \times \mathrm{BR})/\sigma \times \mathrm{BR}$	0.27%	3.7%	1.6%
Combined	$\Delta(\sigma \times \mathrm{BR})/\sigma \times \mathrm{BR}$	0.25%	3.2%	1.3%